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Current Status of Enhanced Recovery Techniques in the Fields of Russia

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Abstract

Russia is one of the main oil producing country in the world with very long history of the oil industry. In one's time in former Soviet Union a lot of attention was paid to oil recovery problems. Unfortunattelly the unfavorable economic climate of the late 1980-s and economic shocks during the period of well-known events in the country in 1990-s caused the rapidly decline of the number of new EOR projects. EOR technologies started to develop in direction of sweep efficiency improvement by cheap agents. Nevetheless by now the very intereresting EOR experience has been accumulated in the country. It is likely that EOR- produced oil in Russia has not already reached its peak level and that it will increase above the current production rates because of improvement of economic situation in the country on the one hand and increasing of mature fields on the other hand.

The paper presents an overview of EOR field experiences in former Soviet Union and Russia for the last 25 years, an analysis of recent efforts and discusses briefly on perspectives for conventional and new EOR methods. The main EOR experiences reviewed are chemical flooding (and flow diverting technologies in particular), gas injection, thermal recovery process, microbiological and unconventional EOR.

Introduction

The problem of enhanced oil recovery is particularly pointed in Russia today: for the last 25-30 years the tendency is from slow to steady decline of the oil recovery factors in the fields. In **Fig.1** a dynamics of oil recovery factors over time is presented for the period 1970-2007, derived by averaging the values of oil recovery factors from a significant number of matured fields. The data fields from different regions of Russia had been used for this analysis.

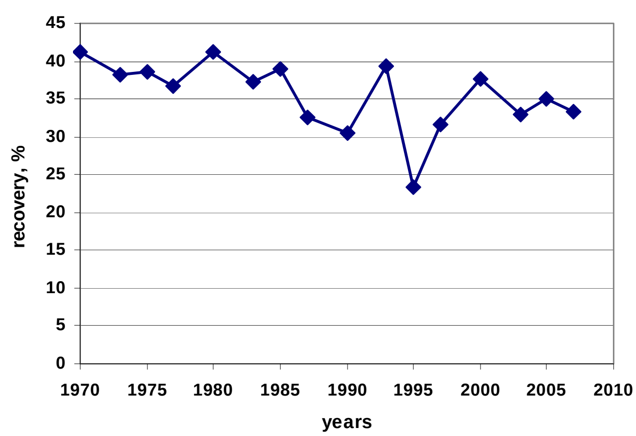

Fig.1 Oil recovery factor dynamics with time in the Russian Federation

The decrease of oil recovery factor in the country can be explained by the change of the so the called "structure of oil reserves", specifically by increase of the share of oil reserves and production volumes from the regions with more complex terrain and climatic conditions and fields with more complex geological conditions: low productive formations and deep-seated accumulations. **Fig.2** shows the change of production share of the main oil producing regions of Russia (Russian Federation) with time (map with main Russian hydrocarbon basins is in **Appendix A**). It is seen from the figure that for the last decades the share of Western Siberian fields has been significantly increased in the total oil production, while production share of European part and Urals area has dropped, i.e. developed regions with good infrastructure. Adverse climatic and geological conditions stipulated the development of fields with less dense well spacing and consolidation of a large number of productive formations in single production targets. All this inevitably results in a sweep efficiency and oil recovery factor decrease.

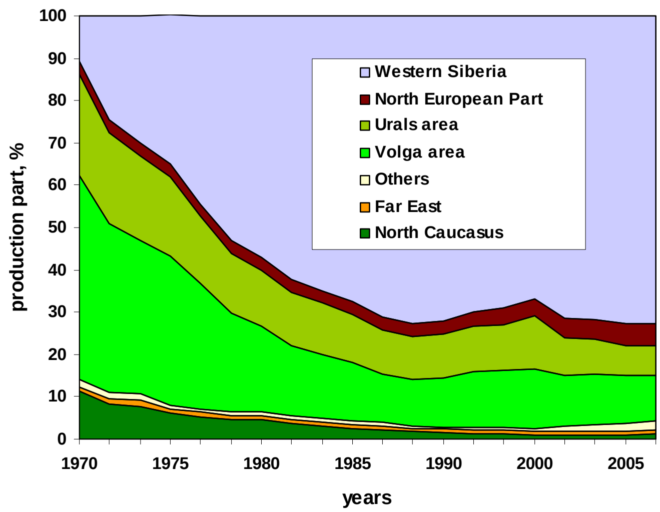

Fig.2 Change of oil production distribution between regions of Russian Federation with time

Economic results of the "Russian perestroika" played a critical role in the decrease of oil recovery factor in mid 1990-s, when investments in the field development and specially in the development of EOR techniques had been significantly reduced.

And finally, the serious factor was the reserves deterioration in the main oil producing region of Russia – Western Siberia. As it is seen from **Fig.3**, only 50% of current reserves could be developed by conventional technologies. The significant share in reserves of Western Siberian fields with already high water-cut formations - 26% and low permeable reservoirs – 25%. The northern part of Western Siberia is characterized by multilayered reservoirs with different fluid saturation and reservoir properties. At the same time main oil reserves in new oil producing regions – Eastern Siberia and Far East are confined to gas-oil and oil-gas accumulations with complex clastic and carbonate reservoirs.

The analysis of oil recovery factors for more than hundred matured fields of the country (with water-cut more than 90%) shows that 50% of the ultimate in-place reserves of these fields are produced with recovery factor from 30 to 35% (**Fig.4**).

Thus, the problem of oil recovery enhancement in Russia is very acute and important.

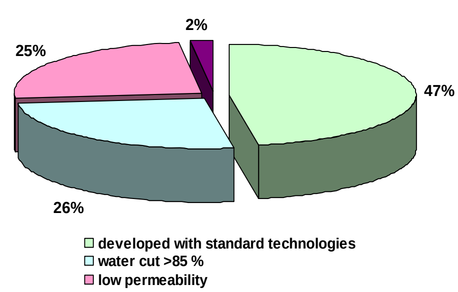

Fig.3. Oil reserves distribution by type in Western Siberia

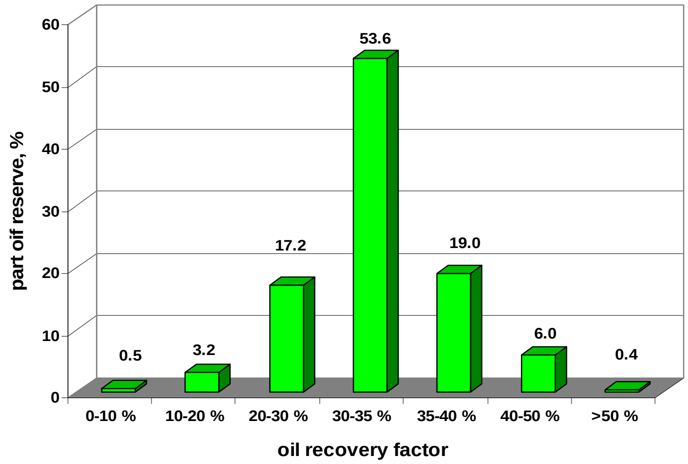

Fig.4. Share of reserves produced in the fields with different values of oil recovery factor

The history of EOR development in former Soviet Union and Russia. Types of EOR techniques applied

Despite an opinion generally held in former Soviet Union a lot of attention was paid to oil recovery problems. In 1976 the USSR government adopted special resolution «On measures ensuring complete oil extraction from the subsurface». The resolution determined the volumes of incremental oil production by tertiary techniques application and also the output volumes of required technical facilities, including special equipment and chemicals. Economic stimulation to perform pilot operations related to EOR techniques implementation was provided. Coordination of R&D activities between industrial and academic institutions by federal and industrial R&D and technical programs which were effective in 80-90-s of the XX century played an important role in EOR development. In 1985 by the Resolution of the Council of Ministers of the USSR a special "Interdisciplinary scientific and technical complex "Nefteotdacha" (since 1994 OAO "NTK "RMNTK "Nefteotdacha") was established. The development and application of EOR techniques was set as priority for all industry R&D institutions.

A serious attention to EOR problem resulted in the rapid growth of the number of implemented projects and also in the volume of incremental oil production through EOR techniques implementation (**Fig.5**). New EOR techniques were developed and existing ones were improved. Unfortunately, not all of them had a widespread application due to some technological and organizational reasons and, therefore, EOR had been developed in specific ways. Economic shocks during the period of well-known events in the end of 90-s caused catastrophic reduction of EOR application. The oil industry restructuring influenced seriously on EOR scale of operations also. Start-up shops and newly-made oil companies needed to get a profit rapidly and couldn't support expensive EOR projects.

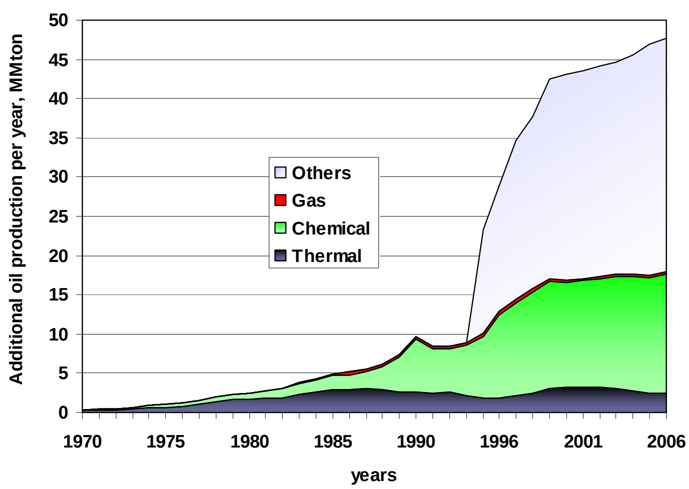

Fig.5 Additional oil production dynamics over time

It should be noted that Russian EOR classification is close to the system recognized all over the world and at the same time it has some differences. Several groups of techniques are determined by the type of oil recovery and working agents applied: so called "hydrodynamic", chemical, gas flooding, WAG, thermal recovery process and others.

It should be said that hydrodynamic EOR is a formation stimulation performed by changing operating regime of producers and injectors (flow rates and production rates, well shutting-in) for redistribution of flow partterns in the formation to involve non-drained formation zones or periodic increase-decrease of the reservoir pressure to ensure water intrusion in low permeable zones of the formation and oil extraction from these zones. Thus, hydrodynamic EOR in a wider sense should be referred to a reservoir management, rather than to EOR. Chemical EOR is split into two separate groups of techniques differentiated by type and volume of formation stimulation: chemical flooding in the common sense and technology of sweep efficiency improvement based on injectors near well zone treatment. The most unclear category in the Russian oil industry is «other EOR techniques»: it may include any stimulation techniques and even bottomhole zone treatments, if they result in sweep efficiency enhancement. In some cases these technologies may include massive hydraulic fracturing (it is assumed that it spreads on non-drained lenses and interlayers) sidetracking (increases the sweep efficiency), and some other techniques which in the common world practice are referred to the reservoir and water management. As a matter of fact, the group of tertiary techniques is not distinguished.

Due to existing conventionality in EOR techniques determination there are different estimates on the total number of EOR projects in Russia and incremental production due to their implementation. Therefore, **Fig.5** represents the data on production dynamics related to EOR application for the last 35 years, including gas, thermal and chemicals EOR techniques. Besides that it also shows the dynamics of incremental oil production for 1995-2006 by implementation of other stimulation techniques which are in the common sense can not be referred to EOR, but nevertheless had been included in the reports of the oil producers as incremental oil production due to impact on formation and bottomhole zone treatments. The situation is getting worse since for the last ten years there was no official statistics available on volumes and efficiency of modern EOR application. According to different estimates[7,8,46], for the last ten years incremental production through modern EOR application was continuously decreasing and now its share in the overall oil production is insignificant. At the same time, according to data from the oil companies incremental oil production in Russia had increased 2.5-2.8 times within 1996-2000 and in some companies it reaches 20% of the overall oil production. This can be explained by the fact that in many companies all interventions (engineering operations) resulting in oil production stimulation and not only in enhanced oil recovery are referred to EOR.

Thus, the current oil production in Russia based on EOR implementation can be estimated as 17-18 MMtons. Here, the main share in production is from chemical EOR - 81-82 %, which is almost fully related to technology of sweep efficiency improvement based on injectors near well zone treatment, but not to chemical flooding. By gas flooding and WAG application 0.35-0.4 MMtons of oil is produced. Total incremental oil production from formation stimulation and bottomhole zone treatments by using other techniques is about 30 MMtons. But of course it can’t be directly accounted as production by EOR methods.

Chemical flooding

Chemical flooding with different types of chemicals started to be tested in the Soviet Union since mid 60-s of the last century, the main scope of field tests was performed in 70-80-s.

Flooding with surfactants “OP-10” application was first time implemented in one of the pilot areas of the Arlanskoye field (Republic of Bashkortostan) in 1964, and then it was applied in some other areas of the Soviet Union fields: Romashkinskoye (which was in the Top 20 of the largest fields of the world according to oil reserves estimates) and Novo-Yelkhovskoye (Republic of Tatarstan), Samatlorskoye and Zapadno-Surgutskoye (Western Siberia), and in some fields of Azerbaijan and Ukraine[38]. At some point the number of pilot areas with surfactant flooding was up to 35-40.

Commercial tests of polymer flooding started in Orlyanskoye field (Volgo-Ural) in 1969. In 70-80s polymer flooding was also tested in Romashkinskoye, Arlanskoye, Kozlovskoe, Radaevskoe, Kuleshovskoe, Deryuznevskoe, Sosnovskoye and Mishkinskoye fields (Volgo-Ural), Kalamas field (Kazakhstan). The total number of pilot areas with polymer flooding was from 25 to 30. The reservoir parameters of these fields were in the wide ranges: depth – 600-2800 m, permeability – 0.15-1.7 μm^2, temperature - 24-87^{0}C, oil viscosity – 1-75 μPa s. Specific oil production (ration of produced oil and injected agent – polymer) amounted to values from 42 to 5000 tons (on average 200 tons).

Large-scale tests of oil displacement by sulfuric acid started in Romashkinskoye field and in several fields located in Tatarstan and North Caucasia in 1969. About 80% out of 37 pilot areas with sulfuric treatments was performed in Romashkinskoye field.

Field tests of alkaline flooding had been performed to a limited extent. The largest and most continuous test started to be performed in Trekhozernoye field (Western Siberia) since 1976. Oil displacement by alkaline solutions was also performed in several small fields of North Caucasia, Perm region and Azerbaijan.

Micellar-polymer flooding started to be tested in two blocks of Romashkinskoye field since 1980.

Despite the significant field test efforts and positive technological results received in many of these tests the number of projects with chemical flooding performed in the Soviet Union gradually had come to zero in early 90-s. The main reason of almost zero application of the chemical flooding was low economic efficiency of the processes due to the oil prices existing at that period of time and costs of implementation of the specified technologies.

On the contrary, the significant interest was in a so called «flow diverting technologies", that represent technology of sweep efficiency improvement based on injectors near well zones treatment. The main benefit of the development of these techniques was primarily the economic factor – insignificant volumes of the chemicals applied, in many cases their low costs and also the simplicity of techniques implementation.

"Flow Diverting Technologies" (FDT)

"Flow Diverting Technologies" or "Flow Deviating Technologies" (FDT) are based on the injection of insignificant volume of special agents into injectors for reduction of high layers flow properties (down to blockage these layers sometimes) and thereby for "redistribution" of injectivity profiles between layers and "smoothing" water displacement front in formation. Mainly FDT are used under high water cut conditions, although in some cases they are applied not only for mature fields. These technologies have been actively used in Russia since 1980-s and nowadays almost all chemical flooding projects in the country are connected with them.

There are variety of FDT types and agents used for these technologies. All flow diverting technologies can be separated in several groups by nature of influence on reservoirs:

- blockage due to gel formation;

- blockage because of precipitation by chemical reaction;

- blockage by particles plugging;

- increasing of displacement agent viscosity.

Also FDP can be classified according to the type of used agents. About 100 existent agents applied in FDT can be categorized as:

- gels;
- polymers and mixtures on the basis of polymers;
- agents reacting with formation fluids;
- agents forming emulsion;
- containing particles fluids;
- high viscosity systems.

By now tens thousand wells in Russia has been treated by FDT on the whole. For large fields the number of the well treatments can be run up to hundreds per year. As an illustration some most interesting examples from hundreds of FDT projects are presented in **Table B-1** (**Appendix B)**. It is necessary to emphasize that as a rule the effectiveness of FDT implementation are estimated as the ratio of produced oil and injected agent or as the additional oil production per one treated well. First of all such estimation approach rides the use of FDT in some separate zones of fields and not for field as whole. Sometime the recovery increment in these zones is calculated also. However such evaluations can be inaccurate even in case of limited and separated zones because of variuos reasons and insignificant reservoir volume involved in the process. Besides in most cases FDT effectiveness is determined by so called "characteristics methods" which are based on the function "cumulative oil production vs. cumulative liquid production". The additional oil production is calculated as difference between cumulative oil production in real and forecasting "characteristics" for the same value of cumulative liquid production. The real characteristic desribes a whole period of reservoir development including period of FDT realization while these period of time in forecasting “characteristics” is determined as extrapolated trend of real “characteristics” curve before FDT beginning. Of course sometime this calculation method accuracy is relatively poor.

Comprehensive evaluation of FDT results in Russia shows the effectiveness of these methods varies greatly. The “specific oil production” value very depends on oil fields parameters and changed in wide ranges (**Table B-1)**:

- blockage due to gel formation: 13 - 5400 tons per 1 treated well (on average 2000-2500 tons) or 400-500 tons per 1 ton of agent;

- blockage because of precipitation by chemical reaction: 800 - 4500 tons per 1 treated well (single instance 32500 tons) or 3-180 tons per 1 ton of agent;

- blockage by particles plugging: 900 - 1200 tons per 1 ton of agent;

- increasing of displacement agent viscosity: 820 - 2200 tons per 1 treated well (single instance 14500 tons) or 191-1550 tons per 1 ton of agent.

Thermal recovery processes

Thermal EOR techniques in former Soviet Union were implemented in 42 projects, including steam treatments which were implemented in 16 sites, fireflooding –11 sites, thermal flooding in 15 sites. Thermal oil recovery was 3.9 MMtons/year on-peak. Nevertheless, despite the lessons learnt from EOR application there was an activity fade-out during post-perestroika period.

Huff-and-Puff: also known as Cyclic Steam Stimulation (CSS) of individual wells is the most commonly used thermal method in high-viscosity oil fields in former Soviet Union[3-5,18]. Huff-and-puff had been applied both as a stand alone method to impact on high-viscosity oil formations and in combination with steam flooding at oil fields in Volgo Urals, Northern Caucasia, Ukraine, Sakhalin and Azerbaijan since 1960. As a rule huff-and-puff antedated all steam flooding processes. Up to 10 cycles of Huff-and-Puff have been used at some fields. However, the effectiveness of this method varies greatly: with additional oil production per treatment varying between dozens to a few thousand tons. The steam oil ratio (SOR) varied from less than 1 to over 10 tons per ton.

As an illustration some examples from dozens of cases of huff-and-puff implementation in Russia and CIS are presented in **Table 1**.

Steam flooding[3,5,24,29] and **hot water flooding**[5,26,27] were the most effective thermal methods used in former USSR. Steam flooding was carried out at the following oil fields: Usinskoe, Okha, Katangli, Yzhno-Voznesenskoe, Zybza-Glubokiyi Yar, Akhtyro-Bugundyrskoe (Russia); Borislavskoe, Skhodnichko-Urichskoe (Ukraine); Kenkiyak, Karazhanbas (Kazakhstan). Hot water flooding was implemented in the following fields: Gremikhinskoe, Mishkinskoe, Usinskoe, Zhirnovskoe, Voyadinskoe (Volgo Urals, Russia), Uzen (Kazakhstan). Hot water injection technologies with some variants were also used for heterogeneous carbonate and clastic formation at fields in Udmurtiya [26,27]:

Some additional variants of hot water & steam flooding included:

- Impact Dosage Thermal Influence (IDTI) – cycling the injection of steam with cold water, or another variation of this method is called IDTIP (with pause before cold water injection);

- Thermal Cycling Influence on Formation (TCIF) – cycling hot water injection in some of producers while continuing production from other producing wells. Another procedure was to change the producers into injectors and injectors into producers after each thermal injection/production cycle

- Thermal Polymer Injection (TPI or sometimes called TPIHE) – this method included injection of hot water with polymers to smooth the flood front.

Two hot water injection examples are demonstrated in **Table 2**.

Thermal mine method was applied in Yaregskoe field[24] The method involves the creation of subsurface mine shafts with galleries from which open hole wells were drilled for steam injection and oil production. The development of the field had been started since 1937. Pay sands with permeability 2-3 mkm^2 lie 130-200 m deep. Oil viscosity is 15000 cP. Production by mining method: 7.4 MMtons from area of 40 MMm^2 from 1937 to 1968. Thermal mine production has been carried out from 1958. By 2003: production - 12,6 MMtons on square 5,8 MMm^2, recovery coefficient - 52,4 %.

Table 1- CSS and steamdrive examples

Fields (region)	Period of time	Oil viscosity, μPa*s	Type of formation and permeability μm2	Depth m	Details of technologies and results of implementation
Okha[5,18] (Sakhalin)	1965-2006	500-700	Clastic 0.1-1.2	80-600	Huff and puff in individual blocks of field started in 1962. Steam flooding in individual blocks was carried out from 1973 to 1987. Total injection: steam: 16.5 MMtons, water: 65.5 MMtons. Additional oil production: 5.6 MMtons (35.7 % total oil production). Steam oil ratio (SOR): 3.0
Usinskoe[4] (Komi, Timan Pechora)	1982-2006	700	Carbonate 0.5-0.7	80-600	Huff and puff used in 1977-1982. Total number of wells treated: 94, average number of cycles: 4. Additional oil production: 0.75 MMtons. SOR: 0.61. Hot water was injected in separate field area. Followed by Steam flooding was started on small area (~10 % of field) in 1982-1993. Total injection: steam - 10 MMtons, water-22.9 MMtons. Additional oil production: 9 MMtons
Kenkiyak[5] (Kazakhstan)	1972-1991	150-700	Clastic 0.01-4.0	350-400	Steam flooding: steam ring (0.6-0.8 PV- porous volume) pushed by cold water (1.7-1.9 PV). Steam flood area included 98 injectors and 607 producers. Additional oil production: 2.83 MMtons. Steam injection:14.9 MMtons.
Karazhanbas[5] (Kazakhstan)	1982-1993	160-660	Clastic 0.35	300-500	Steam flood area included 140 injectors and 656 producers. Additional oil production: 4.42 MMtons. Steam injection: 18.1 MMtons.
Zybza-Glubokiyi Yar[3] (Northern Caucasia)	1974-1980		Clastic	250-350	Huff and puff for 30 wells (2- 7 cycles) was used before steam flooding. Steam flood area included 3 steam injectors, 1 water injectors for push steam ring. 72 producers. Additional oil production: 0.63 MMtons. SOR: 4.6.
Yuzhno-Voznesenskoe[29] (Northern Caucasia)	1978-1990	20-30	Clastic 0,073	600-850	Steam flood area included 5 injectors and 64 producers. Additional oil production: 4.42 MMtons. Steam injection: 0.13 MMtons.

Table 2- Hot water flooding examples

Fields (region), formation	Period of time	Oil viscosity, μPa*s	Type of formation and permeability μm2	Depth, m	Details of technologies and results of implementation
Gremikhinskoe[26, 27] (Udmurtiya, Volga-Ural)	1983-2006	90-180	Carbonate 0.17	1050-1100	IDTI and IDTIP both started in 1985. IDTI: additional oil production: 1.28 Bbtons, hot water volume reduced by two. IDTIP: additional oil production: 1.79 Bbtons, reduction of hot water-oil ratio (HWOR) from 6 to 2.5 by hot water injection. Both technologies resulted in up to a 37 % increase in recovery coefficient (from 29% with standard hot water injection) TCIF: additional oil production: 0.32 MMtons from 1988 to 1998, HWOR:2.8.
Mishkinskoe[26] (Udmurtiya, Volga-Ural)	Since 1973	75	Carbonate 0.2-0.3	1450	TPI: Increasing of recovery coefficient up to 44 % in comparison with 29 % by hot water injection, additional oil production is 283 tons per 1 ton of polymer.

In situ combustion[3,5] was applied as pilot projects at some fields in Russia: Pavlova Gora , Severo-Voznesenskoe, Arlanskoe (Ashitskii block), Romashkinskoe. It was also tried in the following CIS fields: Karazhanbas (in Kazakhstan), Surakhany, Khorasany, Koshanaur (in Azerbaijan), Gnezdinchevskoe (in Ukraine). In most cases (**Table 3**) this method was ineffective for both geological and technical reasons. The main problems were the complexity of monitoring and management of combustion processes in heterogeneous formations.

SAGD. Recently SAGD pilot projects have been started in Yaregskoe fields (Komi Republic) and Mordovo-Karmalskoe field (Republic of Tatarstan). Three pair wells with horizontal section lengths of 300 m are being used on Yaregskaya field. Two wells with horizontal section lengths of 100 m were drilled on Mordovo-Karmalskoe field. Distance between upper injector well and lower producer well is 5 - 7 m in the both cases. Classical SAGD process is being realized in Yaregskoe field while wells at Mordovo-Karmalskoe field are operated in cycling regime – injection-pause-production (already 13 cycles have been completed).

Table 3- In situ combustion examples

Fields (region), formation	Period of time	Oil viscosity, mPa*s	Type of formation and permeability μm2	Depth, m	Details of technologies and results of implementation
Pavlova Gora[3] (Northern Caucasia)	1966-1987	360	Clastic 0.3-2.4	90-270	Pilot project with: 4 injectors, 25 producers. Approximate additional oil production: 70 Mtons. Average air oil ratio (AOR): 1546 m^3/tons. Low sweep efficiency and agents breakthrough were observed.
Romashkinskoe[12] (Tatarstan)	1978-1983	20	Clastic 0.69	1000	Technology: dry in situ combustion with front pushed by cold water. Project was ineffective because of agent breakthrough caused by geological and technological issues. Oil production: 0.526 MMtons by injection of 24.5 MMm^3 air and 1.4 Mm^3 water.
Karazhanbas[5] (Kazakhstan)	1981-1993	160-660	Clastic 0.35	300-500	Pilot project with 67 injectors & 365 producers. Additional oil production: 2,63 MMtons, air injection: 1752 MMm3. Average AOR: 666 m^3/tons. Low sweep efficiency and breakthrough of agents observed.
Severo-Voznesenskoe[5] (Northern Caucasia)	1983-1991		Clastic	460	Pilot project: dry in situ combustion with front push by cold water. Number of wells in block: 1 air injector, 3 cold water injectors & 57 producers. Additional oil production: 57 Mtons, air injection: 59 MMm3. Average AOR: 1022 m^3/tons. Project was ineffective: low sweep efficiency and breakthrough of agents.

So, today hot water and steam injection are being used in Russia in limited number of projects in Komi Republic (Timan Pechora), Sakhalin (the Far East), Republic of Udmurtia and Republic of Tatarstan (Volgo Urals) and two SAGD pilot projects are being carried out in the country.

Gas technologies

Gas injection in the former Soviet Union was performed in a limited number of projects. The largest tests with high-pressure gas injection at miscible displacement had been performed in Goit-Kort and Ozek-Suat fields (North Caucasus, Russia)[10]. Commercial gas injection is now performed in three small fields in Republic of Bashkortostan (Russia) – Ozerkinskoye, Staro-Kazankovskoye and Grachevskoye[23] .

For the first time commercial injection in Russia was performed in Ozek-Saut field (North Caucasus) in 1966. The project was a limited volume formation stimulation. Initially dry hydrocarbon gas was injected under regime of multicontact miscible displacement in one of the Neokomian formations of the field – $XIII_{2+3}$. For several years since 1982 a series of water and gas injection in flooded zones of the other formation – IX had been performed, which was flooded earlier by edge water flooding.

High pressure gas injection in Goit-Kort field started in 1978 and continued till mid 90-s. Before gas injection the field was producing at depletion drive for 22 years and during that time formation XXIII produced 1.9 MMtons of oil with annual average production 87 Mtons. Dry hydrocarbon gas injection in formation XXIII was performed at pressure of 320 Bar and was higher than pressure of oil mixing with gas, providing one-contact miscible displacement. During the injection period nearly 3 MMtons of oil was produced with annual average production of 233 Mtons for the first year of injection, up to 100-110 Mtons at the end of injection. Oil production decrease during gas injection was caused basically by technical reasons – injected gas volume reduction due to compressor equipment depreciation. It is characteristic that average gas factors in the end of injection period were 240-260 m^3/ton and several ones exceeded their initial values. This indicated good gas displacement of oil.

Gas injection projects in Ozerkinskoye, Staro-Kazankovskoye and Grachevskoye fields were started in early 80-s [23]. The main reason for gas technology implementation was the peculiarities of geology these fields and reservios properties:

reefs with high thickness and heterogeneous carbonate formation, bottom water with oxidized oil in oil-water zone, gas cup (**Table 4**). Moderate well infectivity, water breakthrough along high permeability zone and low sweep efficiency were observed during the water injection trial. So these fields have been started to develop without pressure support before gas injection.

Table 4 – Description of fields developed with gas flooding

Parameters	**Fields**		
	Ozerkinskoe	**Grachevskoe**	**Staro-Kazanskoe**
Maximum depth, m	1700	1500	1260
Total thickness, m	250	570	325
Net thickness, m	24	83	25
Porosity, %	0.15	0.14	0.16
Permeability, 10^{-3} μm^2	68	39	430
Initial formation pressure, MPa	16.2	14.5	12.8
Saturation pressure, MPa	10.6	10.4	7.4
GOR, m^3/tons	51.5	98.5	60.5
Initial formation temperature, ^0C	22	23	20
Oil viscosity, mPa·s	1.9	1.9	4.1
Distance between wells, m	200x250	170x170	250x250

Grachevskoe field was depleted within 1958-1982 and than all old wells were abandoned and 102 new wells were drilled with well pattern 200x250 m. Gas flooding has being carried out since 1985 in the form of gravity segregation (gas injection in upper part of dome). With aim to provide better displacement efficiency 371.4 Mtons of LPG was injected into all gas injectors in 1983-1986. Special selective gas isolation workover helped to decrease GOR at the later stage of field development. By now 2500 MMm^3 of gas has been injected and 4.7 MMtons of oil has been produced. Current oil recovery is 32 % instead of 27 % forecasted in case of the field development without pressure support (recovery was 22.9 % at the end of depletion period).

Staro-Kazanskoe field has been developed since early 50-s. Initially 116 wells were drilled with pattern 170x170 m. Two pilot tests with water flooding (1956-1962) and hydrocarbon solvent injection (1978-1982) demonstrated bad results. In 1988 the most part of old wells was abandoned and 72 new wells were drilled. After that gas was started to inject into 6 wells in upper part of two domes. By 2003 the cumulative gas injection volume amounted to 912 MMm^3, additional oil production reached 273 Mtons and oil recovery uncreased over 2 %.

The gas flooding at Ozrkinskoe field has been realized within 1975-1992. Dry hydrocarbon gas was injected into 3 wells with periodic mode and the LPG rims had been created around each of injectors before gas flooding. About 70.8 Mton of LPG and 246 MMm^3 of gas were injected in all. Additional oil production amounted to 408 Mtons, oil recovery augmentation was 9 %.

In Russia WAG process was tested in separate blocks of the Samotlorskoye and Fedorovskoye fields (Western Siberia) and at Romashkinskoye field (Republic of Tatarstan), Bitkovskoye field (Ukraine), and also in pilot areas of several fields in Kazakhstan and Uzbekistan. Now WAG is performed with extremely inighnificant volume of injected agents at Alekseyevskoye field (Republic of Tatarstan)[40] and at two small fields in Western Siberia – Vostochno-Perevalnoe and Sredne-Khulymskoe. WAG is being carried out on single parts of the fields with the use of special low rate boost pumps. Each of these pumps individually supplies separate wells by 1.3-1.5 Mm^3/day of gas-water mixture or foam. Water-gas mixture injection in carbonate fracture porous formation at Alekseevskoe field (Republic of Bashkortostan) is illustrative example of such process. Cycling water-gas mixture and foam system have been injected since 2005. In 2007 total number of injectors in pilot block was increased up to 3. The first result of this trial consisted in the improvement of nearest production well deliverability only.

So it is necessary to note again the limited number of gas flooding and WAG projects in Russia. This fact can be explained both technological and institutional factors: lack of equipment till recently, aspiration to use cheap technologies and etc. Probably the interest to EOR gas technologies will grow due to several reasons: tightened inspection for associated gas utilization (attractive agents for WAG), development of gas injection equipment and moreover constantly state structures requirements to apply EOR at the Russian fields (first of all with gas technologies).

"Hydrodynamic methods"

The influence on fluids flow pattern in formation by means of wells operation conditions changing is considered in Russia as "Hydrodynamic EOR methods". First of all the following technologies can be included in "hydrodynamic EOR methods" category:
- flow path (streams directions) change;
- cycling formation pressure change;
- forced (accelerated) liquid production.

Each of these types of the influence is aimed at recovery one or another kind of residual oil in reservoir. For instance, the flow path change method allows to collect the oil from stagnant zones of reservoir. The cycling formation pressure change provides drainage low permeable zone of formation (porous matrix in case of fractured porous reservoir) during pressure variations. Both of these methods can be carried out by temporally injectors or/and producers shutdown or water injected volume alteration. Forced liquid production method is based on "stripping effect", i.e "residual oil saturation -capillary number" dependence.

As it was mentioned above, so called hydrodynamic EOR in a wider sense should be referred to a reservoir management rather than to EOR. So the hydrodynamic EOR experience description is outside the scope of this article and only some examples for each of these methods are presented here.

"Cycling water flooding with change of flow path" developed in 1964 has been used at many Russian fields in Western Siberia, Volgo Urals and Timan Pechora areas. In 1970-1980 this method was applied at some fields in Volgo-Ural province: Pokrovskoe (1.3 % of recovery increase), Bavlinskoe (5 % of recovery), Alakaevskoe (4 % of recovery), Lyalikovskoe (400 Mtons of additional oil production with water cut decreasing) and many other ones. One of the biggest field in the world - Romashkinskoe field (Republic of Tatarstan) gives the most impressive example of this technology implementation. Cycling water flooding were started in several blocks of the field in 1972 with various modifications: 1- shutdown of rows injection wells (or groups of injectors) for period of time from 1 months to 1 year, 2- temporally separate injectors shutoff or the injected water volume decrease[21]. The flow path change methods in addition to cycling water flooding has been used since 1986 and was based on new injection wells rows switching on. As the complementary impaction so called "pulsed injection" was begun in some blocks of the field in 1989. It consists in production wells shutdown during cycles of water injection and injection stopping in production cycles. As results of such impacts the oil recovery increased in ten blocks of the field in the range from 1.8 to 10.0 %. Today all injectors in Devonian reservoir of the field are operated in cycling regime.

Up to 7 % of producers and 36 % of injectors were involved in cycling watering at the other giant oil fields - Samotlor (Western Siberia).

Cycling pressure change and cycling water flooding are being actively used at oil fields in Volgo Urals hydrocarbons basin and first of all in Republic of Tatarstan and Repuiblic of Bashkortostan. In these regions "hydrodynamic EOR" provides 40-50 % of current oil production from some mature fields[11, 33]. A little bit lower values are declared for some Western Siberian oil fields: 8-10 %[33, 40].

The forced liquid production method has been used at several mature fields in Samarskaya region since the end of 90-s[6]. The main effect of forced liquid production on these fields appears as water cut decreasing for highly watered wells. Additional oil recovery for these fields can reach several units according to forecast calculation.

Microbiological EOR

At present time microbiological EOR has very restricted application in Russia in spite of the fact that microbiological EOR technologies has been developed in the country since the end 80-s. In the beginning microbiological EOR were used in conventional direction: for the improvement of the oil displacement efficiency. At that, both technologies of the microorganisms multiplications in beds were used: 1- microorganisms implantation in formation from the surface together with nutrients and 2 - natural microflora activation in formation by nutrients supply. One of the first pilot microbiological EOR project was realized at Bondyuzhnoe field (Republic of Tatrstan) in 1983. After that within 1992-1994 microbiological

EOR method was used at Romashkinskoe field for one of the block with high viscosity oil (100 mPa s by temperature 20^0C). Two stages technology was applied for injection molasses and bacterium Clostridium tyrobutyricum in reservoir[22]: stage 1- aerobic microflora activation in bottom hole of wells with the form of residual oil biodegradation products (fatty acids, alcohol, surfactants, CO2 and i.e.), 2- water flooding with pushing of created agent in formation. During pilot field test 1 Mtons of molasses solution was injected and 4.8 Mtons of oil was produced.

Then microbiological methods were used in some fields in Republic of Tatarstan (Pervomyiskoe, Novo-Elokhovskoe, several blocks of Romashkinskoe fields and others), Republic of Bashkortostan (Sergeevskoe field) and Western Siberia (Bystrinskoe and Solkinskoe fields). By now several different microbiological EOR technologies have been developed and applied with quite good results at mentioned above fields (**Table 5**)[22].

Table 5 – Results of microbiological EOR

Technologies	Period of time	Producers/Injectors number	Additional oil production, Mtons
Formation microflora activation	1983-2002	19/70	150.2
Combined microbiological influence with cycling watering	1992-2002	16/50	287.6
Molasses (Clostridium)	1992-1995	6/25	4.8
Formation microflora activation with additional hydrocarbon supply	1992-2002	13/38	42.0
Formation microflora activation including alien crops	1994-2002	15/35	23.7
Formation microflora activation with additional oxygen supply	2000-2005	48/138	68.2
Total	1983-2005	117/356	576.5

At present time the interest to microbiological agent is growing as applied to flow diverting technologies. Some laboratory experiments showed the opportunity to decrease formation permeability by bacteria metabolites during their reproduction[25]. This phenomenon can be used for treatment of near well bottom zones with aim to partially blockage high permeability layers which are the channels of water breakthrough. Well bottom zone treatments by microbiological agent “IAI” (“active silt” produced from biological treatment facilities) were done in pilot projects in several fields in Republic of Tatarstan (Romashkinskoe, Bavlinskoe and Novo-Elokhovskoe fields) and Republic of Bashkortostan (Tayimurzinskoe and Arlanskoe field). In all 68 producers and 54 injectors were treated by agent “IAI” with average additional oil production per one treated well equal to 288-1080 tons for carbonate and 512-2756 tons for clastic formation.

So, there are single instances of microbiological EOR technologies used in Russia despite the fact that many modifications of these technologies have been developed and tested. As results only a little more a half million tons of additional oil has been produced by microbiological EOR for 25 year throughout the country.

Unconventional EOR

The impact of various “physical fields” (acoustic, electromagnetic and etc.) on oil reservoirs are considered in Russia as unconventional EOR. The first trial of acoustic and vibratory impacts in Soviet Union were started in the middle of 70-s for well productivity improvement. According to various estimations about 10,000-15,000 wells have been stimulated in various regions of the country over a period of time since 1970-s. Mainly these treatments were aimed at cleaning of the near well bottom zones or increasing of the formation permeability locally around wells by means of pressure pulses creation. Sometime other effects were produced: heating of very narrow zone around wells (some dozens centimeters) or changing of formation fluids properties in this zone. Different downhole oscillators (vibratory generators) were used: powder-charge and thermo-gas-chemical pressure generators, electric-hydraulic and hydro-electro-acoustic sources of oscillations, wave-jet pressure generators and hydrovibrators. As a rule these oscillators had rating from units to tens kilowatts and frequency from units to tens KHz and could transfer significant energy into the well bottom zones. So, in many cases well stimulation jobs were successful and wells productivity was restored or improved.

Wells vibratory stimulation combined with the flow diverting technology is being tested now at Yugomashivskoe field in Republic of Bashkortostan[11]. Downhole hydrodynamic generators are installed into 6 injectors on this field for infectivity index improvement.

First trial of vibroseis impact on reservoir from the surface was done on Abuzy field in Krasnodar Region (North Caucasia) in 1986. The main idea of this influence was the consolidation and remobilization of residual oil in watered zones of formations. Since then vibroseis impact has been tested at 6 fields in former Soviet Union and Russia with the use of 1-2 surface sources (rating 60 KWt) or so called waveguide into wells. The common data of these pilot tests are presented in **Table 6** according to monography[30]. Additional oil production in these fields by the vibroseic impact amounted to 3-300 Mtons.

We have some doubt in these results because of uncertainty in the physical aspects of influence and effectiveness estimation. There are essential problems with transmission from surface into formation the necessary amount of energy because of its dissipation in upper rocks.

Table 6 – Results of vibroseis impaction

Field	Region	Depth, m	Period of time	Additional oil production, Mtons
		Russia		
Zhirnovskoe	Volgograd region	1000	1991-1993	300
Mancharovskoe	Republic of Baskortostan	1400		22
Samodurovskoe	Orenburg region	1900	1995-1996	50
Berozovskoe	Orenburg region	1930	1994-1995	20
Kiengopskoe	Republic of Udmurtiya	1530	1997-1998	5
		Kyrgyzstan		
Changyrtash	Kyrgyzstan	410-570	1987	3

Conclusion

On the basis of the presented analysis of the history and current state of EOR in Russia, we offer the following conclusions:

- A lot of EOR pilot projects with various modifications of the recovery methods have been carried out in former Soviet Union and Russia. Economic shocks during the period of well-known events in the early of 1990-s caused catastrophic reduction of EOR application. Today in the country there are not many projects related to EOR in a general recognized all over the world sense. Yearly additional oil production by means of real EOR methods is estimated at units MMtons. Additional production by so called 'flow diverting technologies" is considered a several times greater.

- The actual state of affairs can be explained both technological and institutional factors. Till recently in many respects Russian oil industry was evolved in "extensive way of evolution" which consists in bringing into development new fields and "assimilation of new oil territories". Intensive EOR efforts were made only in old hydrocarbons basin in European part of the country. Hands-on experience with financing of EOR projects since early 90-s forced oil companies to use cheap EOR technologies. In this respect so called 'flow diverting technologies" and "hydrodynamic EOR" with their extremely low CAPEX and OPEX turned out an excellent way out. However these technologies couldn't be recognized as panacea for essentially oil recovery improving because they don't provide a true impact on residual oil in the whole volume of reservoir. Moreover very often the positive results from various reservoir management solutions "run up an account" of these technologies.

- Undoubtedly the oil price increasing will stimulate development of EOR technologies in Russia. Lack of tax remissions for additional oil produced by EOR methods was serious obstacle for EOR development in the country. Nowadays state of affairs is changing: the tax remission for natural bitumen and heavy oil production has been constituted; taxes are classified in conformity with degree of oil fields depletion. Nevertheless the improvement of tax regulations and special tax stimulation needs for futher EOR development.

- Gas technologies, WAG and combined technologies (chemical flooding and FDT) can be considered as perspective EOR methods in Russia in the future.

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*) Oil Industry Journal– in Russian language

Appendix A

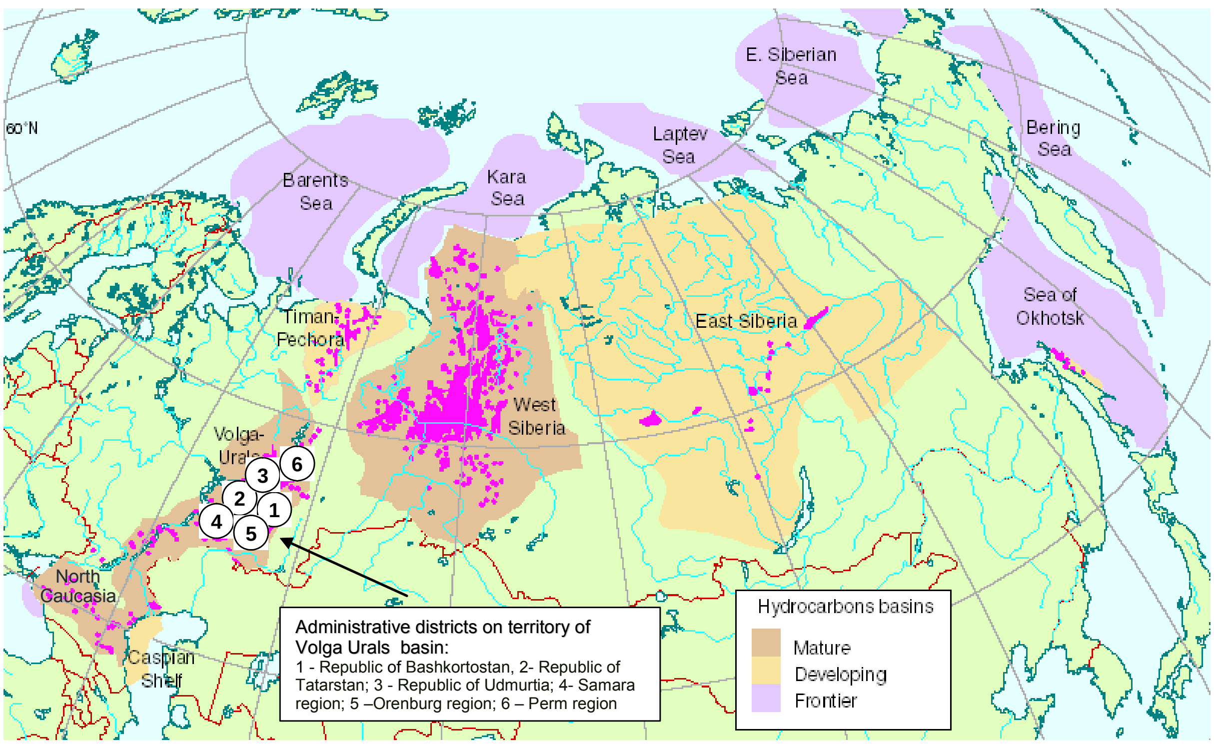

Fig.A-1 Russian hydrocarbons basins map

Appendix B

Table B-1 – DFT implementation results

Type of reagent	Type of influence	Agent composition	Number of treatments	Additional oil production*)	Field (region or area)	Period of time
Ammonia water[15]	precipitation growth	24% ammonia solution	110	871 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	1986-1991
			45	13 tons/tons	Novokhazinskii block of Arlanskoe field (Republic of Bashkortostan)	1986-1989
PDS[13,14,16,17,39] (polymer-disperse particles system)	gel	polymer+ disperse particles	218	4180 tons/ treated well	Lokosovskoe, Ur'evskoe, Potochnoe, Las-Eganskoe, Pokachevskoe, Uzhno-Pokachevskoe (Western Siberia)	1986
			123	5400 tons/ treated well	Samotlorskoe (Western Siberia)	1986
			91	2731 tons/ treated well	Fedorovskoe (Western Siberia)	1988
			13	2477 tons/ treated well	Talinskoe (Western Siberia)	1990
			8	785 tons/ treated well	Povkhovskoe (Western Siberia)	1990
			492	2188 tons/ treated well	Romashkinskoe, Novo-Elkhovskoe, Bavlinskoe (Republic of Tatarstan)	1981
			21	1457 tons/ treated well	Chetyrmanskoe, Arlanskoe, Sataevskoe, Serafimovskoe, Igrovskoe, Uzhno-Maksimovskoe, Shkapovskoe, Voyadinskoe (Republic of Bashkortostan)	1986
			67	1148 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1987
VDS [9, 14, 36, 39]	gel	wood meal +mud powder	4	33 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	80-90-s
				3965-7830 tons/ treated well	Samotlorskoe, AV and BV formation (EWestern Siberia)	90-s
Polymer[13,14] (polyacrylamide)	viscosity increase	polyacrylamide	13	843 tons/ treated well	Balykskoe (Western Siberia)	90-s
			3	826 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	80-90-s
			7	2214 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	80-90-s
Alumino-chloride[15]	precipitation growth	Alumino-chloride	-	addional 5 Mtons of oil	Novokhazinskii block of Arlanskoe (Republic of Bashkortostan)	1995
Biopolymer "Simusan"[13]	gel	polymer	14	157 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	90-s
Alkali-silicate solution[13]	precipitation growth	alkali-silicate solution	40	2525 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	1986-1991
Viscous-elastic liquid[39]	gel	polymer	90	1060 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1993
			609	721 tons/tons	Deryuznekovskoe (Samara region)	1988
Polymer "Temposcrin"	gel	polymer	-	1500-2500 tons/tons	Uzen (Kazakhstan)	1992
				1236 tons/ treated well	Bobrovskoe (Orenburg region)	1993
				5000 tons/ treated well	Barsukovskoe, Novopurpeyiskoe (Western	1995

					Siberia)	
				2000 tons/ treated well	Ust-Balykskoe (Western Siberia)	1997
Liquid glass +HCl+ polyacrylamide [20, 39]	gel	Liquid glass +HCl+ polyacrylamide	8	17 tons/tons 710 tons/ treated well	Arlanskii block of Arlanskoe field (Republic of Bashkortostan)	1993-1995
			3	23.54 tons/tons, 4020 tons/ treated well	Berezo-Nikolskii block of Arlanskoe field (Republic of Bashkortostan)	
SSS [36, 44] (sulphate-soda system)	precipitation growth	sulphate- soda system	5	1730 tons/ treated well	Mamontovskoe (Western Siberia)	90-s
			9	2143 tons/ treated well	Yuzhno-Balykskoe (Western Siberia)	
Surfactant “Ekstract-700”	emulsion	surfactant		1137 tons/ treated well	Yuzhno-Balykskoe, AS formation (Western Siberia)	1993-1995
				1394 tons/tons	Petelenskoe, BS formation (Western Siberia)	
				1833 tons/tons	Malo-Balykskoe, AS formation (Western Siberia)	
Liquid glass +HCl+ chemicals[20]	gel	Liquid glass +HCl+ waste of chemicals plant “Kaustik”	1	-	Arlanskii block of Arlanskoe field (Republic of Bashkortostan)	1993-1995
			2	12,51 tons/tons 1645 tons/ treated well	Berezo-Nikolskii block of Arlanskoe field (Republic of Bashkortostan)	
OS[36]	precipitation growth, SiO2	NaSiO3+electrolyte (CaCl2, NaCl)	-	180 tons/tons, 5001 tons/ treated well	Samotlorskoe (Western Siberia)	90-s-early 2000
SS[36]	precipitation growth, gipsum CaSO5	NaSO4+electrolyte	-	4164 tons/ treated well	Samotlorskoe (Western Siberia)	90-s-early 2000
Polyatomic alcohol[31]	precipitation growth	polyatomic alcohol	-	454 tons/ treated well	Several fields in Republic of Bashkortostan	1994
“ODS” [36] (disperse system for precipitation growth)	precipitation growth + particles plugging	NaSiO4+electrolyte (CaCl2, NaCl)+ wood meal	-	4557 tons/ treated well	Samotlorskoe (Western Siberia)	90-s
“GeOs” [9, 36] (gel-precipitation growth mixture)	precipitation growth, SiO2	NaSiO3+electrolyte (CaCl2, NaCl)	-	3559 tons/ treated well	Samotlorskoe (Western Siberia)	90-s-
Nepheline[31]	precipitation growth	aluminum silicate natrium	-	1678 tons/ treated well	Several fields in Republic of Bashkortostan	1995
Polymer[35]	viscosity increase	polymer	9	1551 tons/tons	Orlyanskoe (Republic of Bashkortostan)	80-s
			15	191 tons/tons	Sosnovskoe (Republic of Bashkortostan)	80-90-s
			3	493 tons/tons	Romashkinskoe, bobikovskii formation (Republic of Tatarstan)	1981
			16	14500 tons/ treated well	Novo-Khazinskii block of Arlanskoe field (Republic of Bashkortostan	80-s
polymer + surfactant[13]	viscosity increase	polymer + surfactant	9	950 tons/ treated well	Novo-Khazinskii block of Arlanskoe field (Republic of Bashkortostan	80-s
SAS [34, 39] (silicate alkali solution)	precipitation growth	silicate alkali solution	93	2000 tons/ treated well	Novo-Khazinskii block of Arlanskoe field (Republic of Bashkortostan	80-90-s
			63	1600 tons/ treated well	Arlanskii and Berezo-Nikolskii blocks of Arlanskoe field (Republic of Bashkortostan)	80-90-s
			14	1700 tons/ treated well	Mancharovskoe (Republic of Bashkortostan)	80-90-s
			4	1800 tons/ treated well	Igrovskoe (Republic of Bashkortostan)	80-90-s

APS[39] (alkaline polymer solution)	gel	Alkaline polymer solution	17	1100 tons/ treated well	Серафимовское Republic of Bashkortostan)	80-90-s
			19	1200 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	80-90-s
			65	700 tons/ treated well	Nartovskoe (Republic of Bashkortostan)	80-90-s
Lignine[1,34]	viscosity increase	hydrolyzed lignine+ alkaline	7	1400 tons/ treated well	Arlanskoe (Republic of Bashkortostan)	80-90-s
			2	1000 tons/ treated well	Volostnovskoe	
SST (sulfate waste)+KOP-1 [9, 44]	precipitation growth	sulfate waste "SZhK"+acid	30	139 tons/tons	Mamontovskoe (Western Siberia)	90-s
SST (sulfate waste)+CaCI2 [9, 44]	precipitation growth	sulfate waste "SZhK"+acid	9	72 tons/tons	Yuzhno-Balykskoe (Western Siberia)	90-s
			3	125 tons/tons	Ust'-Balykskoe (Western Siberia)	90-s
			4	33 tons/tons	Ust'-Balykskoe (Western Severo-Salymskoe (Siberia)	90-s
			6	12 tons/tons	Pravdinskoe (Western Siberia)	90-s
SST (sulfate waste)+CaCI2 +HB[9, 44]	precipitation growth	sulfate waste "SZhK"+acid + ammonia-tar liquor	1	3 tons/tons	Pravdinskoe (Western Siberia)	
			2	30 tons/tons	Ust'-Balykskoe (Western Siberia)	
SSS (sulfate soda system)+CaCI 2 [44]	precipitation growth	sulfate soda+acid	12	136 tons/tons	Aganskoe (Western Siberia)	
"GALKA" [2]	gel	aluminate + carbamide + additions	-	40-60 tons/tons	Several fields in Pravdinskoe Western Siberia	1990-1992
AF-12+gel[32]	gel+ surfactant	aluminium sulphate + carbamide + surfactant (AF-12)	-	4400 tons/ treated well	Sutorminskoe (Western Siberia)	90-s
"ShPSK" (alkaline polymer culture system) [36, 45]	gel	slurry + alkaline + polyacrylamide	43	1258 tons/ treated well	Var'eganskoe (Western Siberia)	2000-2003
Swelling polymer[28]	gel	polymer	1	1152 tons/ treated well	Nurlatskoe (Republic of Tatarstan)	90-s
"ShPSK-2" (alkaline polymer culture system) [36, 37]	gel	slurry + alkaline + polyacrylamide +methacin	46	924 tons/ treated well	Koshilskoe, Khokhryakovskoe, Permyakovskoe	2000-2001
			75	1929 tons/ treated well	Megionskoe, Vatinskoe, Severo-Pokurskoe, Yuzhno-Aganskoe (Western Siberia)	2000-2003
			43	1312 tons/ treated well	Var'eganskoe (Western Siberia)	
"GFE" (hydrophobic emulsion эмульсия) [39]	emulsion	Surfactant + oil wetting agent	11	400 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1998
Liquid glass+ chloric acid [20, 39]	gel+ПАВ	liquid glass+ chloric acid	1	401 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1998
"HTI" [39]	viscosity increase	polyglycol + isopropyl alcohol	4	5559 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1984
Rubber grit +chemicals[39]	particles plugging	rubber grit +chemicals "slamel"	4	7336 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1996
Biopolymers[39]	gel	polymer	14	1369 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1996
Silicate-polymer gel[20, 39]	gel	polymer +liquid glass	16	373 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1995

Alkine waste of caprolactam production[36]	viscosity increase	Alkine waste of caprolactam production (ShPSK)+GOK	2	120 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1995
OEC [39]	gel	oxyethyl-cellulose	17	4265 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1986
CDS (colloidal disperse system)	gel	Olyoxyethylene glycol + mud powder	2	1688 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1993
Rubber grit[20, 39]	particles plugging	rubber grit	27	911 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1991
Alkylated sulphuric acid[20, 39]	precipitation growth	sulphuric acid	9	32428 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1974
SPS (cross-linked polymer)[35, 39]	viscosity increase	polymer	21	686 tons/ treated well	Abdrakhmanovskii block of Romashkinskoe field (Republic of Tatarstan)	1996
”ShDZh”(alkine “distillered” liquid [43]	precipitation growth, gipsum	“distillered” liquid		water cut decreasing	Buzov’yazovskoe, Urshakskoe (Republic of Tatarstan)	90-s
“BP-92”biopolymer[42]	gel	biopolymer	8	1375 tons/tons	Pokamasovskoe (Western Siberia)	90-s
			13	1230 tons/tons	Severo-Pokurskoe, formation BV-6 (Western Siberia)	
			13	577 tons/tons	Severo-Pokurskoe, formation BV-8 (Western Siberia)	90-s
			9	682 tons/tons	Yuzhno-Aganskoe	
			11	714 tons/tons	Vatinskoe (Western Siberia)	90-s

[*)] tons/treated well – 1 ton of additional oil per 1 treated well; tons/tons – 1 ton of additional oil per 1 ton of injected agent